1.—Petroleum Exploration in Western Australia; Past, Present and Future

Presidential Address, 1970

by Phillip E. Playford

Historical Review

Interest in finding oil in Western Australia was first aroused soon after the turn of the century, when supposed traces of oil were reported from the Warren River area, near the south coast. Three holes were drilled during the period 1902-04, but without success. Since this first short-lived boom there have been many ups and downs in oil exploration, and it was not until 1967, 65 years after the first well was drilled, that commercial production began in this State, at Barrow Island.

The main turning points for oil exploration in Western Australia were the discoveries at Rough Range in 1953, and at Barrow Island in 1964. Prior to the Rough Range find many sceptics maintained that oil could not be found in this State, and this discovery did a lot to encourage people, not only among the general public, but also among professional oil men, that commercial fields could indeed be found. Barrow Island was of course even more important, as it was the first oil discovery to be proved commercial.

After the Warren River drilling there was little further activity until 1918, when traces of oil were reported from a water bore being drilled on Gogo Station in the Kimberley district. This report was confirmed by a geologist, and as a result the Freney Kimberley Oil Company was formed to prospect for oil in the Kimberleys. The company drilled a number of holes between 1922 and 1941, when it had to cease operations because of the war.

Modern exploration commenced in Western Australia in 1952, when West Australian Petroleum Pty. Ltd. (Wapet) began operations. This company had been formed to take over permits that had been acquired by Ampol in 1947.

The company had dramatic success in December 1953 with its first well, Rough Range no. 1. Great hopes were held that large commercial fields would be proved in the Exmouth Gulf area. However, subsequent drilling showed that the Rough Range field covers only a few acres and is non commercial. Had the well been drilled on the original site selected by geologists it would have been dry, but it was moved a few hundred feet for easier site preparation, thus placing it exactly over the tiny field. This was a piece of "luck" that was financially unfortunate for the company, as it resulted in a great deal of dry-hole drilling that would never otherwise have occurred. However, although Rough Range was not a commercial success, it spurred exploration throughout Australia.

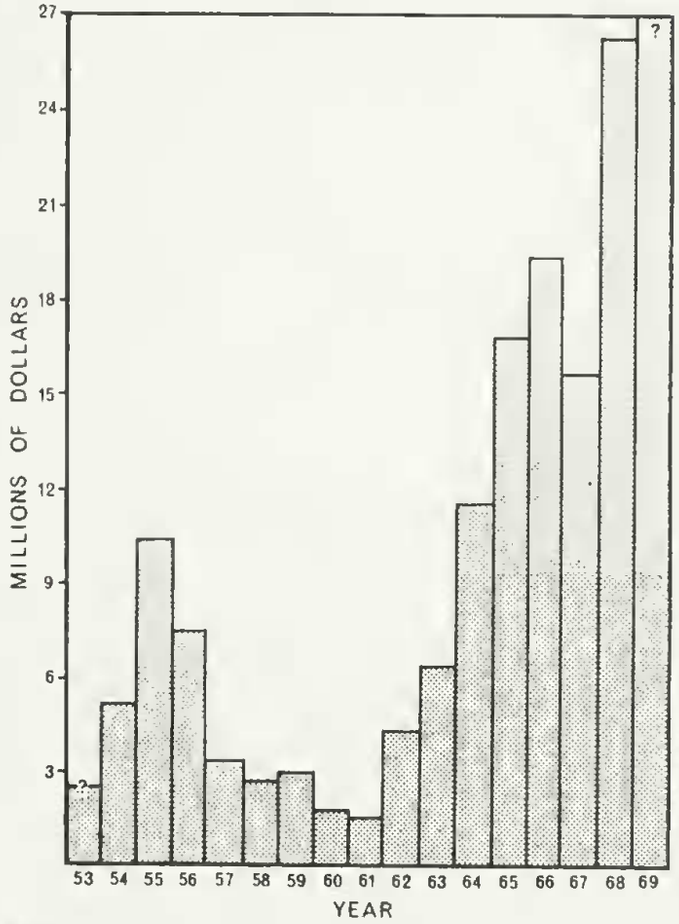

Figure 1.—Petroleum exploration expenditure in Western Australia, 1953-1969.

During the period of enthusiasm after the Rough Range discovery, exploration expanded throughout the State's sedimentary basins. However, this enthusiasm waned with the lack of further success in the Exmouth Gulf area, and no additional fields were found elsewhere in the State. Over the next 8 years exploration gradually tailed off, until the trough was reached in 1961 (figures 1 and 2). Then in that year oil was found at Moonie in Queensland, and just as with Rough Range, this discovery stimulated exploration throughout Australia. Of course the Moonie find had no bearing on the oil prospects in Western Australia, but it is remarkable the psychological impact made by such discoveries, not only on the public, but also on the directors of some major oil companies. Consequently, the Moonie discovery was followed by an increase in exploration expenditure in Western Australia, and this led up to the Barrow Island discovery in 1964. Barrow Island proved

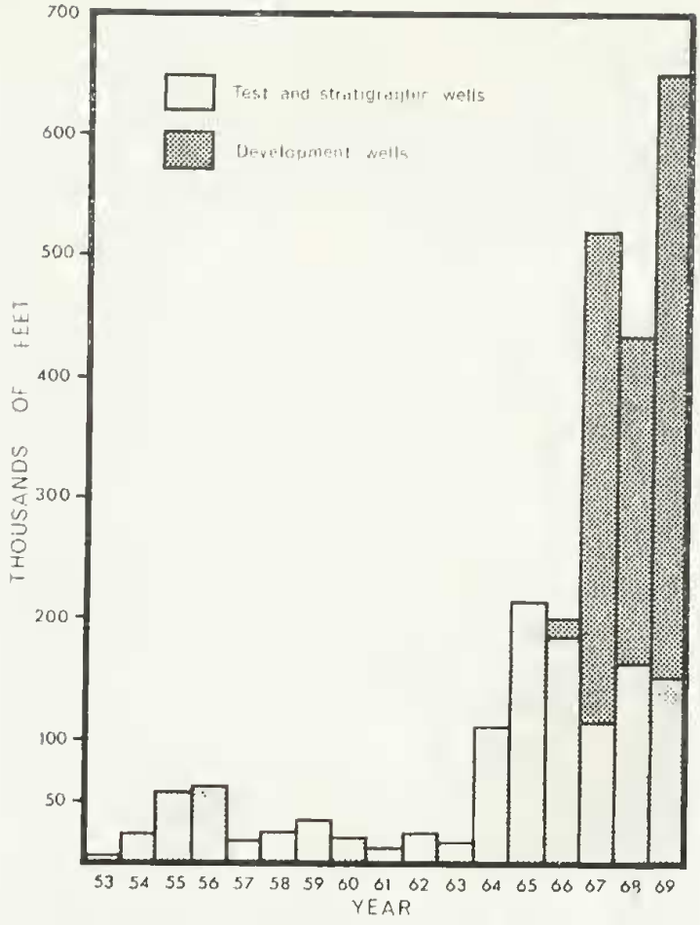

Figure 2.—Petroleum drilling in Western Australia, 1953-1969.

to be the State's first commercial field; the initial shipment of crude oil leaving the island in 1967. Actually a few months before this discovery oil and gas had been found at Yardarino in the Perth Basin. Yardarino is only a small field, but it will be developed commercially next year, as there are plans for linking it to the Dongara-Perth gas pipeline.

The Barrow Island discovery initiated the third period of exploration in Western Australia, which is continuing to the present. It has been marked by a big increase in expenditure on oil exploration and development in this State (figure 1). Several further discoveries have been made, notably those of gas at Dongara, Gingin, and Mondarra, all of which are to be developed for the Perth-Kwinana-Pinjarra market. The pipeline from these fields is expected to be completed late in 1971.

Another significant discovery of oil was made in 1968 in Legendre no. 1, the first offshore well drilled in the State. Today the major part of expenditure on exploration in W.A. is in the offshore areas, which probably have the best potential for future major discoveries.

More detailed information on the history of petroleum exploration in Western Australia is contained in the following publications: Hobson (1936), Playford and Johnstone (1959), Bureau of Mineral Resources (1960), and Playford (1966). The stratigraphy and structure of the sedimentary basins of the State is summarized by McWhae and others (1958).

Exploration Permits

Nearly all of the prospective sedimentary areas of Western Australia are covered by petroleum exploration permits. The principal permit holder is West Australian Petroleum Pty. Ltd., which has farmed out large areas to Continental, Total, and Union. Other large permit holders are the B.O.C.-Woodside-Mid Eastern-Shell-BP-Calasiatic consortium, which holds large areas of the continental shelf in the Carnarvon, Canning, and Browse Basins, and the Arco-Aquitaine partnership, which holds much of the offshore Bonaparte Gulf Basin.

The offshore permits are controlled jointly by the State and the Commonwealth. Under the terms of the Petroleum (Submerged Lands) Act, 1967, offshore permits may cover no more than 400 5-minute blocks, or about 10,000 square miles. The initial period of tenure for each permit is 6 years, and at the end of that period 50% of the area must be relinquished, with further 50% relinquishments of the remainder after each succeeding 5-year period. The onshore areas are controlled by the Petroleum Act, 1967, which is only now being implemented. Permits may cover no more than 200 blocks or about 5,000 square miles. After the initial tenure of 5 years 25% of each permit must be relinquished, with further 25% relinquishments (of the total original area) after each succeeding 5-year period. Both onshore and offshore permits carry specified work commitments which must be met year by year.

In the long term the effect of these acts should be to spur exploration throughout the State. Very large permits have been held for many years by companies that have done little or no work over big portions of their concessions. This will no longer be allowed now that the permit areas are to be broken into smaller blocks which will have to be either explored systematically, or relinquished. The most effective way for a company to continue holding an interest in an area on which it cannot or does not wish to spend further money is to arrange a farmout. As a result we can expect that more farmout deals will be made in Western Australia during the next few years.

Figure 3 shows the Phanerozoic sedimentary basins of Western Australia and the positions of exploratory wells that have been drilled.

Sedimentary Basins

The sedimentary basins cover about 43% of the land area of the State and about 90% of the continental shelf. This is a total area of about 650,000 square miles. More than half of this, in the Bonaparte Gulf, Browse, Canning, Carnarvon, and Perth Basins, is believed to have moderate to good prospects for petroleum. The potential of the rest of the sedimentary areas is regarded as being low.

Perth Basin

The Perth Basin (figure 4) is a long narrow trough of sediments extending north-south for some 600 miles. The eastern boundary is the great Darling Fault, one of the major structural features of the earth's crust. The basin is strongly faulted throughout. Most faults have

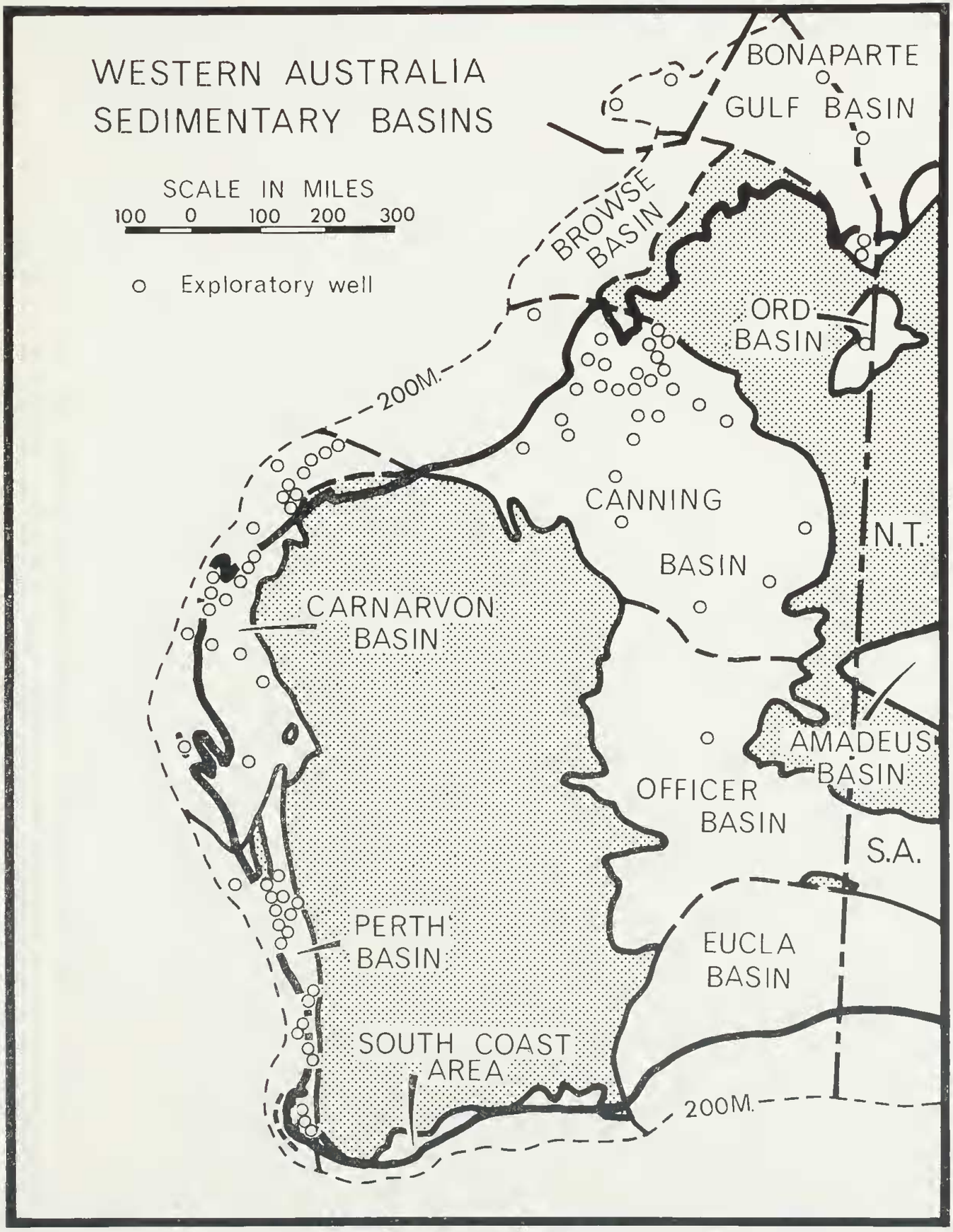

Figure 3.—Sedimentary basins of Western Australia.

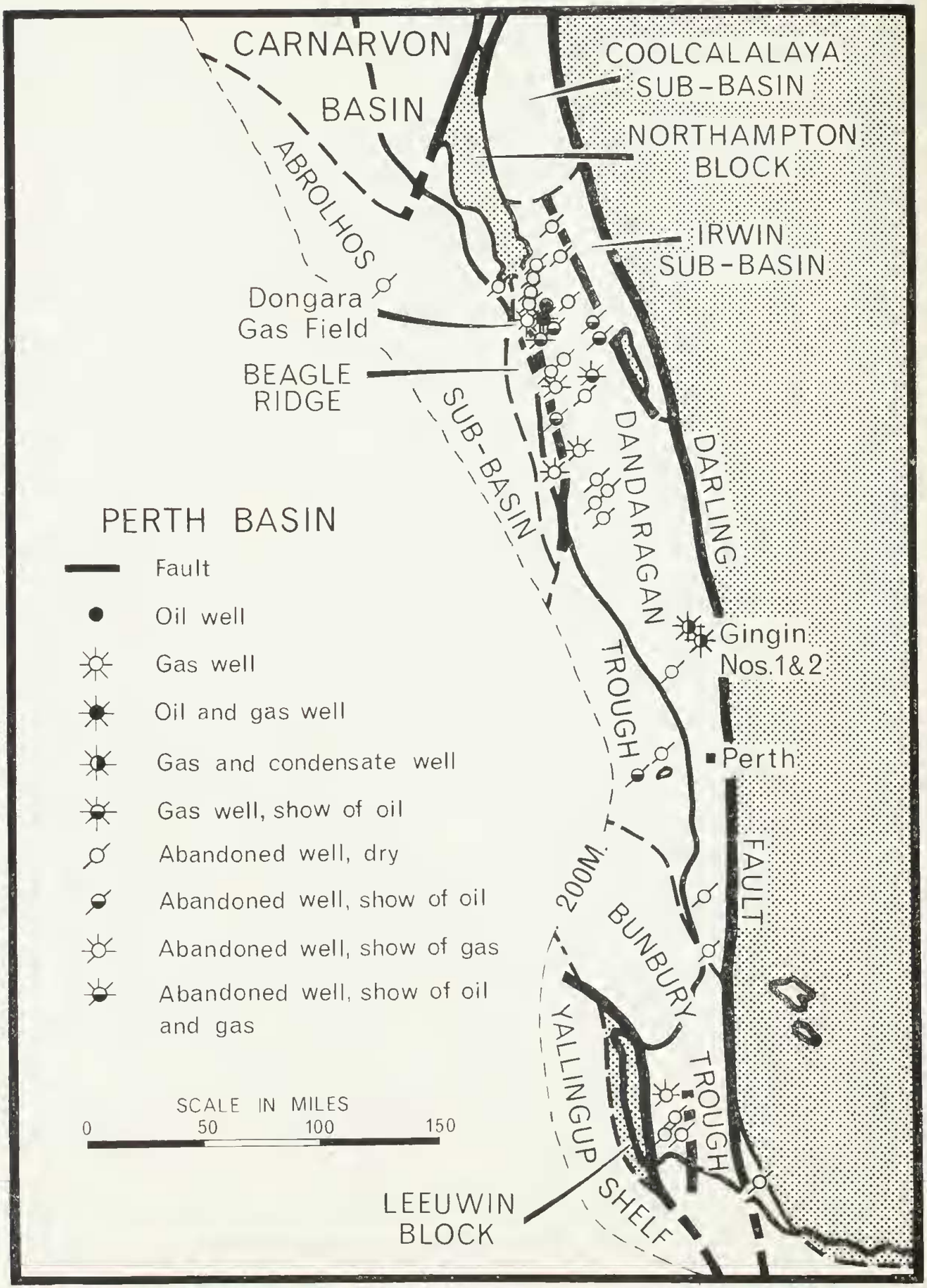

Figure 4.—Perth Basin, showing stratigraphic-structural provinces and exploratory wells.

northerly to north-northwesterly trends, and they are thought to have normal displacements. No simple antielinal struetures are known; those that have been reeognized are assoeiated with faults. The Gingin Anticline is the largest known strueture in the basin, being about 30 miles long and having 4,000 feet of elosure.

The total thickness of the Phanerozoie seetion in the Perth Basin probably exceeds 40,000 feet, and the sediments are of Silurian, Permian, Triassic, Jurassic, and Tertiary age. Mueh of the seetion is paralic to eontinental, the eontinental deposits being largely of fluvial origin, shed from the active Darling Fault. The best prospeets are in the Cretaceous, Jurassic, Triassie, and Permian sequenees.

The most important field found to date in the Perth Basin is the Dongara gas ficld (figure 5). All but 4 of the 19 wells drilled to date by Wapct at Dongara have produeed gas or oil, with daily yields of up to 10 million cubic feet of gas and 1,400 barrels of oil. Produetion is obtained from the Lower Triassie Yardarino Sandstone and from sands in the Lower Permian Irwin River Coal Measures, at depths of around 5,500 feet. The field oeurs in an antielinal flexure eovering about 10 square miles, bounded on the east by the Mountain Bridge Fault. This fault has a displaeement (down to the east) of about 2,000 feet. The distribution of oil and gas wells in the field ean probably best be explained by a combination of small-scale faulting and stratigraphie complications. Details of the structure are difficult to determine beeause of the poor results obtained from seismic surveys, resulting from a surface eover of Coastal Limestone.

Wapet, through its subsidiary Wang (West Australian Natural Gas Pty. Ltd.), has announeed plans for development of the Dongara gas field for the Perth market. A 14-ineh gas pipeline will be constructed to link the Dongara, Yardarino, Mondarra, and Gingin fields to Perth, Kwinana, and Pinjarra. The Company has announeed that it has reserves suffieient to supply gas at 70 to 80 million cubie feet per day for 15 years. The reserves of the Dongara field (by far the largest of the fields to be developed) are believed to be about 500 billion eubie feet. These reserves are relatively small considering the potential of the industrial market around Perth, but more gas diseoveries ean eertainly be expeeted in the northern Perth Basin. The reserves are nearly treble those of the Roma fields that supply Brisbane (about 180 billion cubie feet), but they are mueh less than those of the Moomba-Gidgealpa fields supplying Adelaide (about 1.4 trillion eubic feet), or the Bass Strait fields supplying Melbourne (about 3.5 trillion cubie feet).

The resrves of oil at Dongara are rather small, and the eompany has announeed no plans for their eommereial use.

The nearby Yardarino and Mondarra gas fields are much smaller than Dongara. Both produee from the Lower Triassie Yardarino Sandstone, at around 7,500 feet at Yardarino and 8,900 feet at Mondarra. The full extent of the Mondarra field has not yet been determined by drilling.

The Gingin gas and eondensate field oeeurs in a very large antielinal structure. Produetion is from low-permeability sands in the Lower Jurassic Cockleshell Gully Formation, between 12,680 and 13,630 feet in Gingin no. 1 and slightly deeper in no. 2. The first well was the best produeer, yielding up to 3.84 million eubie feet of gas and 47 barrels of eondensate per day. The permeability of the sands is very low, and produetion deelined with prolonged testing, espeeially in Gingin no. 2. However, it has been reported that the Gingin field will also be tied to the gas pipeline. Production could possibly be stimulated by fraeturing the low-permeability sands, but their depth poses teehnologieal problems. The produetivity of the field eannot be reliably estimated at this stage.

Other small non-eommereial diseoveries have been made in the Perth Basin in Gage Roads no. 1 offshore well (oil, from the Lower Cretaeeous South Perth Formation), Mt Horner no. 1 (oil, from the Lower Triassic Koekatea Shale), Arrowsmith no. 1 (gas, from the Lower Permian Carynginia Formation), and Whieher Range no. 1 (gas, from the Permian Sue Coal Measures). Minor quantities of oil and gas have also been obtained from a number of other wells.

The pereentage of wells that have eneountered showings of hydroearbons is higher in the Perth Basin than in any of the other Western Australian basins, yet it was the last of the major basins in whieh serious exploration was commenced. The best prospects in the basin are probably in the Abrolhos Sub-basin, the northern and western parts of the Dandaragan Trough, and the northern part of the Bunbury Trough.

Carnarvon Basin

The Carnarvon Basin (figure 6) overlaps the Yilgarn Block on the east, and is limited by the eontinental slope on the west. It eovers about 45,000 square miles onshore and 42,000 square miles offshore. The maximum aggregate thickness of sediments in the basin may exceed 65,000 feet, although the maximum thiekness at any one plaee is probably not more than 35,000 feet. The sediments are of Silurian, Devonian, Carboniferous, Permian, Triassie, Jurassie, Cretaceous, and Tertiary age. Most of the section is marine, apart from a thiek unit of sandstone of probable Silurian age at the base, whieh is interpreted as being at least partly eontinental. The Cretaeeous and Jurassic sediments have produeed oil and gas, and there are also prospects in the Palaeozoic and Triassie sequences.

The most eonspieuous struetural feature of the Carnarvon Basin is the series of anticlinal folds developed in Tertiary and Cretaeeous roeks along the western margin, in the Gaseoyne, Exmouth, and Barrow Sub-basins. The largest of these is Cape Range Antieline, whieh is 60 miles long and has a structural relief of some 1,500 feet. These structures are believed to have developed during a late Tertiary and Pleistocene period of eompression. Mueh of the basin is strongly faulted. The boundary between the Wandagee Ridge and the Merlinleigh Sub-basin is one of the fundamental struetural features of the basin. It is marked by an *en echelon* series of faults whieh throw down to the east, although

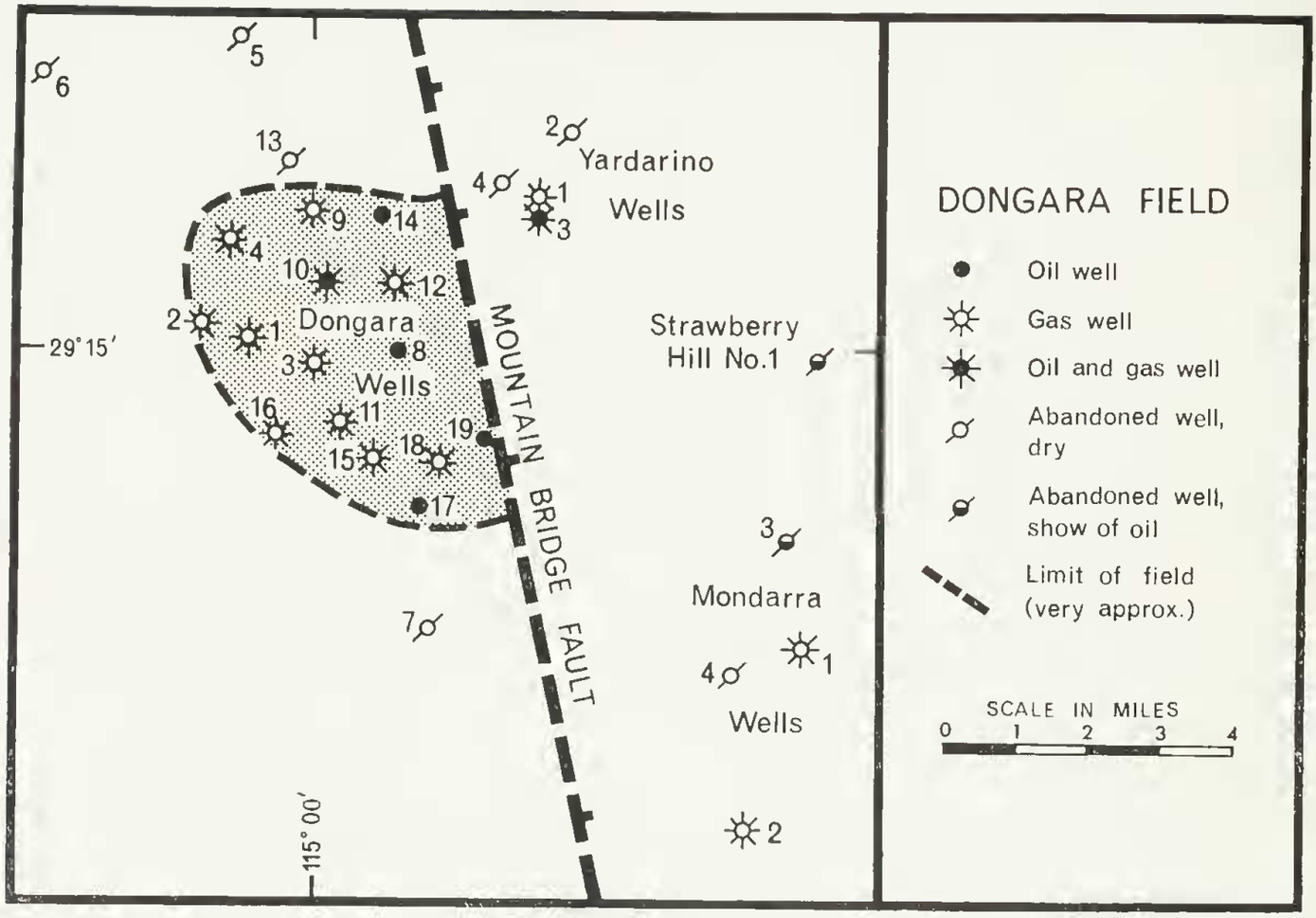

Figure 5.—Dongara gas field.

there has been a small amount of reverse movement (down to the west) along several of them in the late Cainozoic. The Merlinleigh Basin to the east is marked by thick Permian and Carboniferous deposits, and these are thin or absent along the Wandagee Ridge and in the Gascoyne Sub-basin.

Exploration in the Carnarvon Basin was initially concentrated on the belt of Tertiary folds, especially those in the region around Exmouth Gulf (figure 7). As previously discussed, the Rough Range discovery was shown to be uneconomic. A lot of holes were also drilled without success on the huge Cape Range structure and in the intervening area between the two anticlines, although a moderate gas flow was obtained in one of the Cape Range wells.

Other surface anticlines to the south of Rough Range and Cape Range were drilled, but all proved to be dry. By 1958 only one major surface anticline remained, well to the north of Rough Range, at Barrow Island.

In 1964 a well was drilled near the surface culmination of the Barrow Island structure (figure 8), and it resulted in an oil discovery. The principal production was obtained from paralic Jurassic sands at about 6,700 feet. Subsequent drilling has shown that these sands are largely gas bearing and are discontinuous in distribution. However, during the drilling programme to evaluate the Jurassic reservoirs it was found that some thin low-permeability sands in the Cretaceous sequence at around 2,000 feet could produce oil and gas. This reservoir is referred to as the "Windalia Sand", although it is now recognized as being part of the Muderong Shale. It has been developed as the main producing horizon at Barrow Island, yielding some 97% of the present daily production of 47,500 barrels. This field covers about 24,700 acres. It is limited to the south by a normal fault. The average thickness of the producing interval is 44 feet, and production is obtained from sands with permeabilities of 5 millidarcies or less. The in-place reserves amount to some 900 million barrels, and of this about 240 million barrels may be recovered. Production is stimulated by sand fracturing, and a secondary-recovery programme of water injection has been implemented. The oil is a light paraffin-base crude (36° A.P.I. gravity). The average production per well from the Windalia reservoir is about 145 barrels per day. In addition to the daily production (July, 1970) of 47,500 barrels of oil, the field also produces 28 million cubic feet of gas. The company has installed compressors for gas-lifting Windalia crude oil in some wells. To date (July, 1970) approximately 40 million barrels of oil and 28 billion cubic feet of gas have been produced. The maximum rate of production, 50,000 barrels per day, is expected to be reached later in 1970, when the full complement of 324 wells is in production.

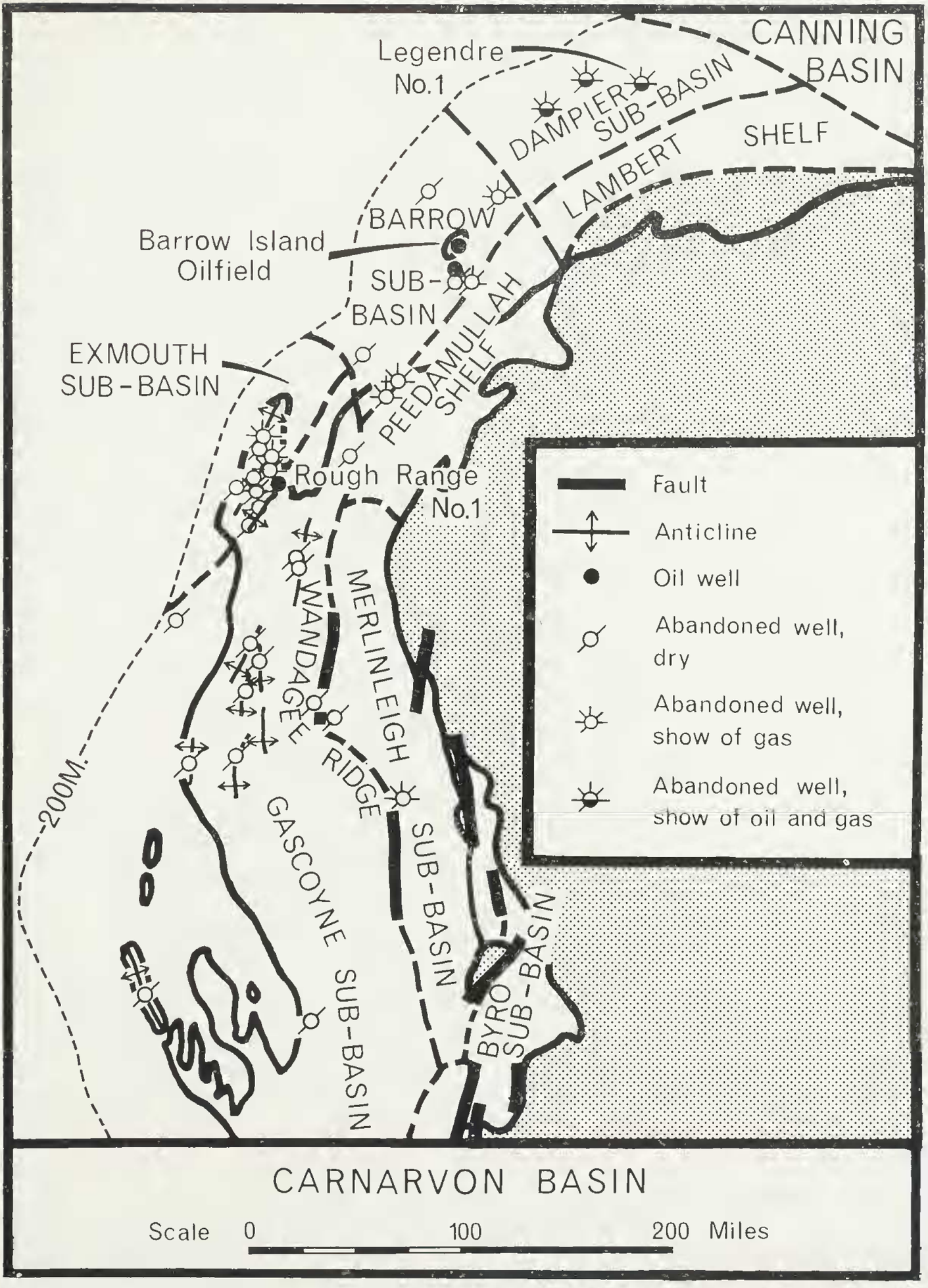

Figure 6.—Carnarvon Basin, showing stratigraphic-structural provinces and exploratory wells.

Oil discoveries have also been made just south of Barrow Island in the Pasco nos. 1 and 3 wells. They produce from Jurassic sands, but have not yet been developed commercially.

Another significant discovery was made by the B.O.C. consortium at Legendre no. 1 well (figure 6). It produced up to 1,014 barrels per day from around 6,200 feet in the Lower Cretaceous sequence. Although the well was abandoned as non-commercial because of the thinness of the producing sand, it is possible that other thicker sands will prove productive nearby. The Dampier and Madeleine wells drilled after Legendre had encouraging oil and gas showings from the Cretaceous and Jurassic sequences, but the section was tight. These wells have shown that a thick sequence of hydrocarbon-bearing sediments occurs in the Dampier Sub-basin, and there are good prospects that commercial production will eventually be obtained in the area. More drilling can be expected in the vicinity of Legendre and further to the southeast.

Wapet's exploration programme in the Barrow Sub-basin has been very disappointing since the Barrow Island discovery. It seemed very probable that oilfields would occur in some of the anticlinal structures the company had defined by marine seismic surveys, but to date none have proved productive. Commercial fields should occur in this area, but it now seems that accumulations are more likely to be stratigraphic rather than structural.

The most likely areas in the basin for major oil accumulations remain in the Barrow and Dampier Sub-basins, despite the recent disappointments there. In addition to the Cretaceous and Jurassic, the Triassic is believed to have potential in those areas. Of the remaining provinces, the Exmouth Sub-basin, Peedamullah Shelf, and the offshore part of the Gascoyne Sub-basin probably have the best potential. Results of exploration in the rest of the basin have not been encouraging.

Canning Basin

The Canning Basin is the largest sedimentary basin in Western Australia, covering 160,000 square miles on land and 45,000 on the continental shelf (figure 9). The aggregate maximum thickness of Phanerozoic sediments in this basin may exceed 45,000 feet. The section is mainly marine and is of Ordovician, Silurian?, Devonian, Carboniferous, Permian, Triassic,

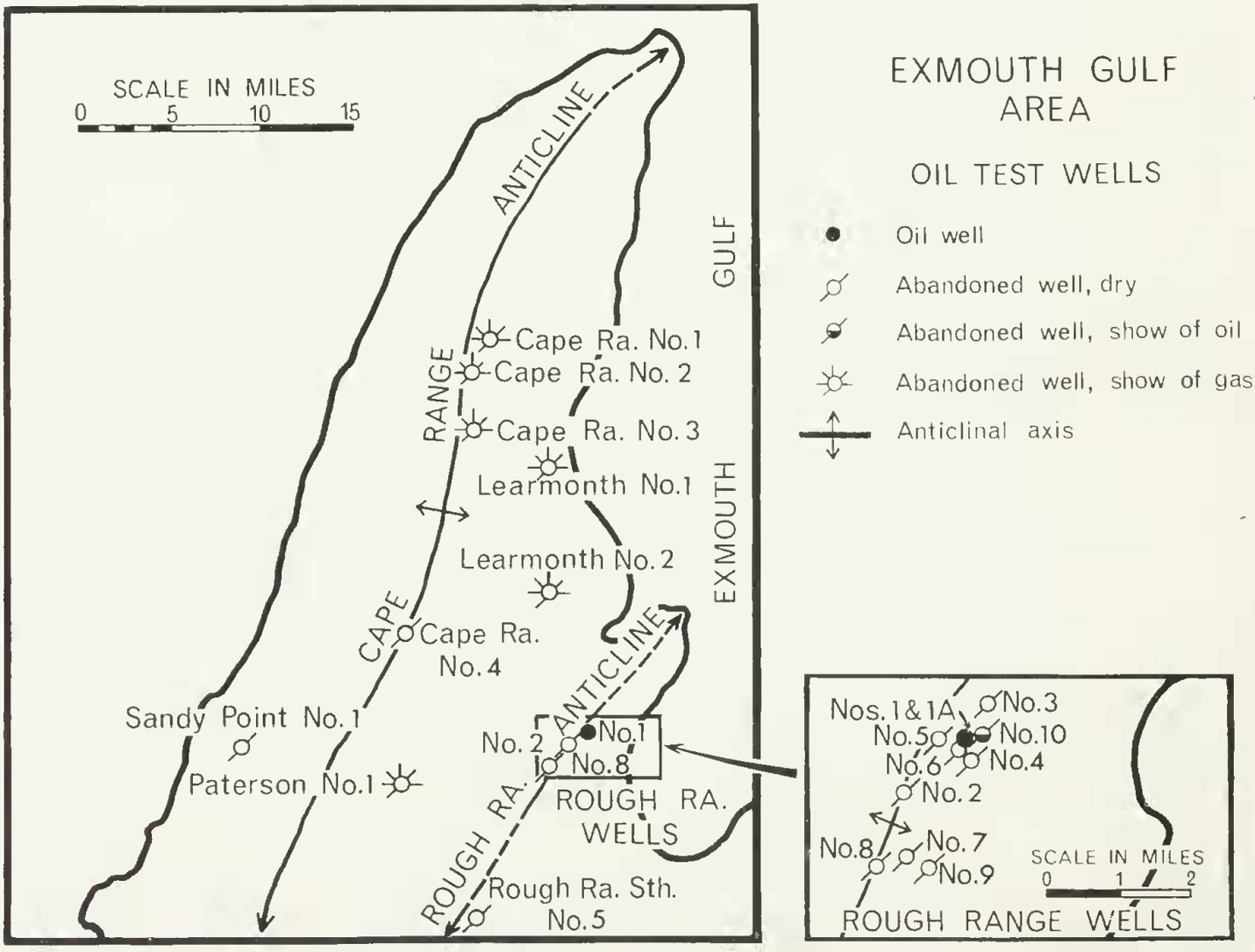

Figure 7 —Exmouth Gulf area, showing exploratory wells.

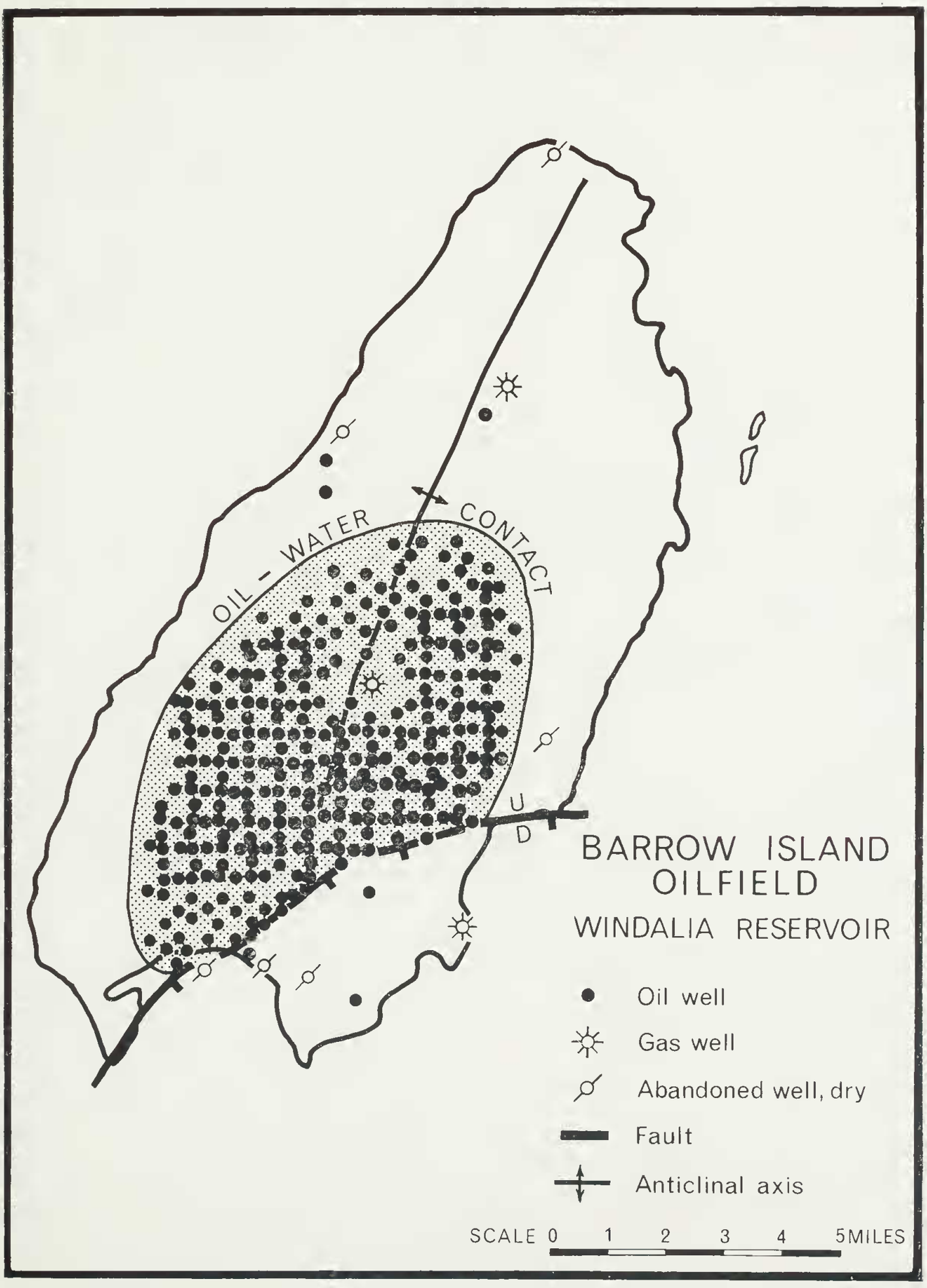

Figure 8.—Barrow Island oilfield.

Jurassic, and Cretaceous age. Tertiary sediments are believed to occur offshore. Exploration to date has been disappointing, and no fields have been found. However, this exploration is very thinly spread over such a huge basin, and with its thick sequence of marine sediments there should be some large fields. Encouraging showings of petroleum have been obtained from deposits of Ordovician, Devonian, and Carboniferous age. The Mesozoic section offshore is expected to closely resemble that of the northern Carnarvon Basin, and is therefore likely to have a high potential.

Exploration has been less intensive in the Canning Basin than in the Perth and Carnarvon Basins, and the stratigraphic-structural sub-divisions shown on figure 9 are not well controlled.

Exploration was initially concentrated by Freney and Wapet on the large surface anticlines of the Fitzroy Trough, a deep graben containing thick Carboniferous and Permian deposits. Wells drilled to date have all been dry, and there is little incentive to drill further holes on the large anticlines. The best showings of oil and gas in the basin were obtained in Meda no. 1 well, drilled near the southern margin of the Lennard Shelf. A few gallons of oil were obtained from the Lower Carboniferous Fairfield Formation, and a small gas flow was obtained from the underlying Upper Devonian reef complex.

Minor showings of oil have been obtained from cores and cuttings of wells drilled in the Ordovician sequence of the Broome Platform.

From the limited amount of information available at present on the Canning Basin some generalizations can be made about the potential of the various provinces. The best prospects may be offshore, especially in the Mesozoic sequence. The Fitzroy Trough appears to be a poor prospect, as already discussed. The Devonian reef complexes of the southern margin of the Lennard Shelf are believed to have moderately good prospects, as is the Jurgurra Terrace. There has been some encouragement on the Broome Platform, and parts of it may have moderate prospects. Too little is known about the Kidson Subbasin and the Anketell Shelf to satisfactorily appraise their potential.

Bonaparte Gulf Basin

The Bonaparte Gulf Basin is partly in Western Australia and partly in the Northern Territory and the Commonwealth Territory of Ashmore and Cartier Islands (figure 10). Only a small part of the basin lies onshore, and most exploration has been concentrated on the continental shelf. The maximum aggregate thickness of sediments in the onshore part of the basin is about 19,000 feet, and at least an additional 15,000 feet is thought to occur offshore.

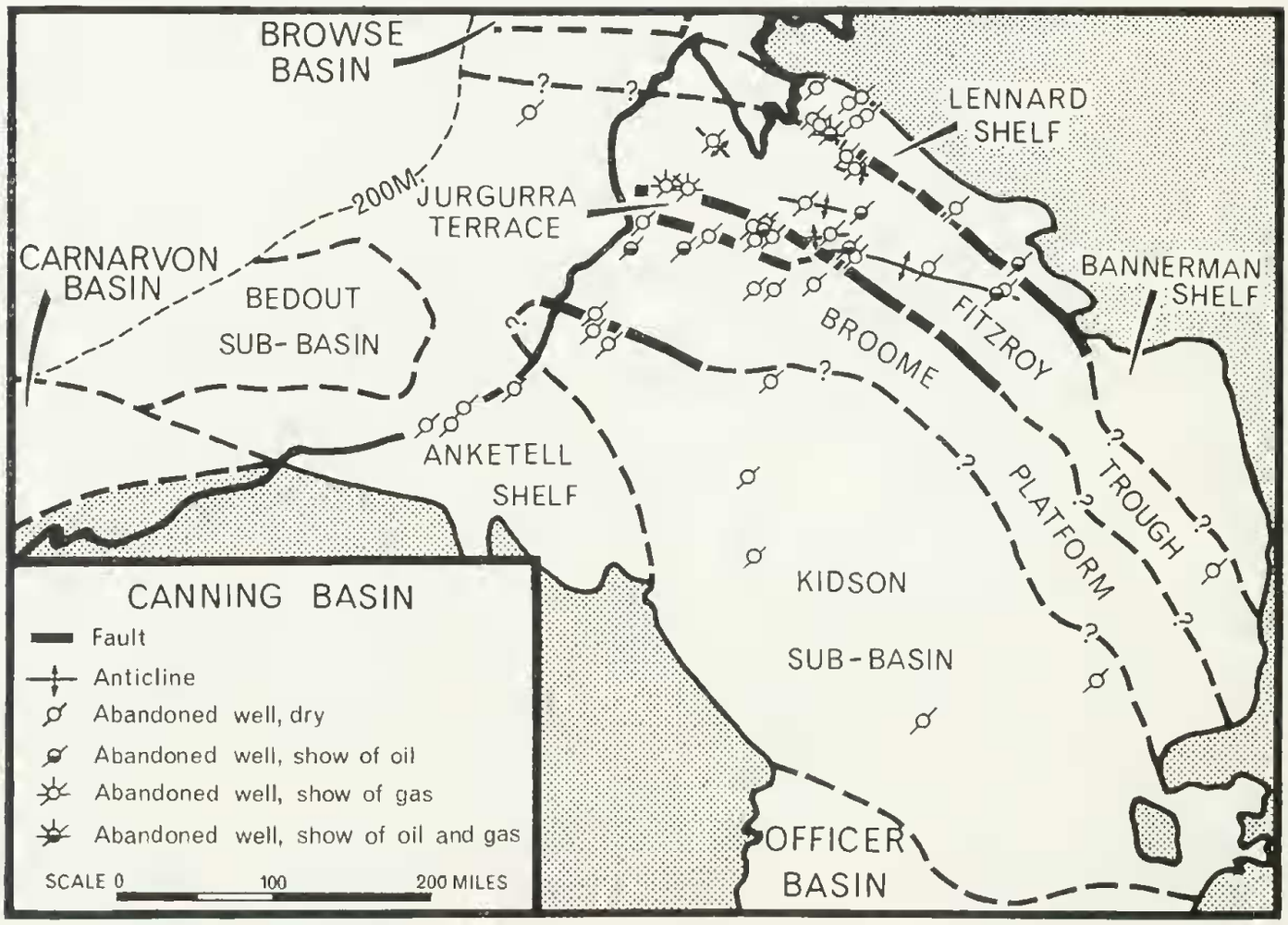

Figure 9.—Canning Basin, showing stratigraphic-structural provinces and exploratory wells.

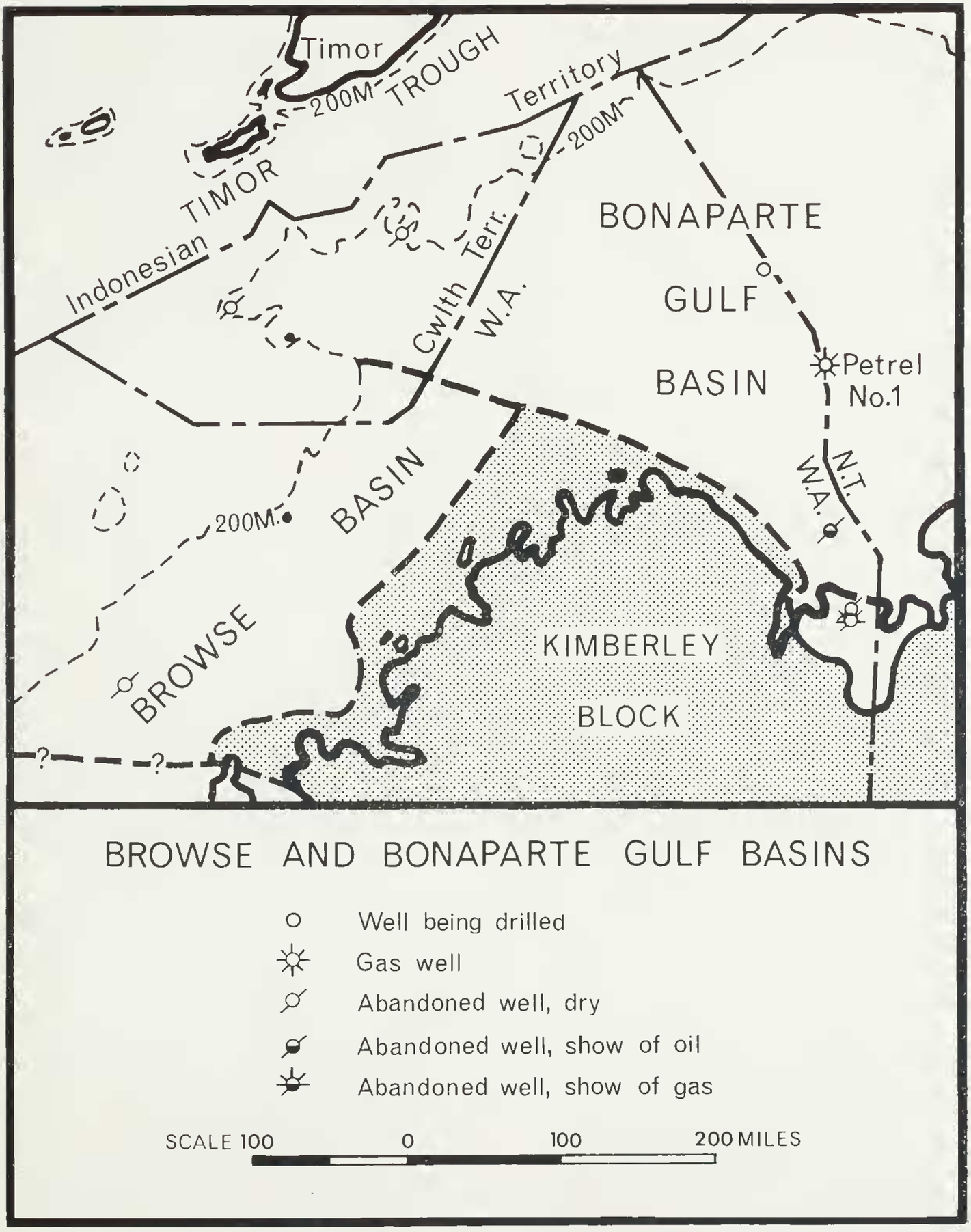

Figure 10.—Browse and Bonaparte Gulf Basins, showing exploratory wells.

The rocks are of Cambrian, Ordovician, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, and Tertiary age. The best prospects are believed to be in the Devonian, Carboniferous, Permian, and Mesozoic sequences.

Exploration has been conducted on a limited scale in the onshore Bonaparte Gulf Basin in Western Australia. The quality of seismic data has been poor, and the two test wells drilled, Bonaparte nos. 1 and 2, were not structurally well controlled. Bonaparte no. 2 had a small gas flow, but it was abandoned as non-commercial. One offshore well has been completed in Western Australian waters, Lacrosse no. 1, and this had encouraging oil shows in the Permian sequence. Another well, Gull no. 1, is being drilled by Arco-Aquitaine. The two wells drilled in the Territory of Ashmore and Cartier Islands, Ashmore Reef no. 1 and Sahul Shoals no. 1, had no significant hydrocarbon shows, However, an important gas discovery was made in Arco-Aquitaine's Petrel no. 1 well, just over the border in Northern Territory waters. This well blew out at a depth of 13,057 feet in Upper Permian rocks. The gas is dry, and the well is blowing at a rate of several million cubic feet per day. A relief well, Petrel 1A, is being drilled nearby, and it is hoped to kill the blowout late in 1970.

The offshore Bonaparte Gulf Basin is believed to have a high potential for the discovery of major petroleum reserves.

Browse Basin

Available data on the Browse Basin are rather meagre. Geophysical results suggest that the basin contains up to 20,000 feet of Phanerozoic sediments (presumably Tertiary, Mesozoic, and Palaeozoic). One dry well, Leveque no. 1, has been drilled, but details of the section penetrated have not yet been made public.

Ord Basin

The Ord Basin in Western Australia and the Northern Territory contains 2,500 feet of Cambrian and Devonian? sediments resting on basalts of probable Lower Cambrian age. One of the first oil test wells drilled in Western Australia, the Okes Durack bore, was put down on an anticline in the basin during 1924. It was dry, and there has been no further exploration since then.

Amadeus Basin

Very little of the Palaeozoic Amadeus Basin extends into Western Australia, and this part is believed to have no petroleum prospects.

Officer Basin

The Officer Basin occupies some 120,000 square miles in Western Australia, and a further 30,000 square miles in South Australia. The total thickness of sediments in the Western Australian part amounts to at least 20,000 feet, but only 3,000 feet of this is known to be Phanerozoic, consisting of Permian, Jurassic, and Cretaceous deposits. The underlying section has been presumed to be Proterozoic, but it is possible that part is in fact older Palaeozoic.

Hunt Oil Company carried out extensive geophysical exploration in the Officer Basin from 1961 to 1966. The company also drilled four stratigraphic wells and put down a single test well, Yowalga no. 2, in 1966. As this well encountered presumed Proterozoic rocks at shallow depth, Hunt decided to withdraw from the area.

Despite the discouraging results of the Yowalga well, the oil prospects of the Officer Basin cannot be completely written off, although they must be regarded as low.

Eucla Basin

The Eucla Basin contains a thin sheet of Cretaceous and Tertiary sediments, having a maximum thickness of 3,000 feet (in the offshore part). Three stratigraphic wells have been drilled, and there has been a small amount of geophysical exploration. The conclusion reached was that the section is everywhere too thin and lacking in structure to have any oil prospects. Attention then turned to the continental shelf, where Tenneco carried out a marine seismic survey. This work showed that the offshore section is also thin and lacking in structure. The thickest section, amounting to about 3,000 feet, occurs in a channel or graben near the shelf margin. The Genoa-Hartog group has recently conducted a seismic survey over this feature.

Future Exploration

Most exploration today in Western Australia is being carried out in the offshore areas, but it is expected that activity will increase onshore once the exploration permits are finalized under the new Petroleum Act.

Moving now to the future, I am optimistic that large reserves of petroleum will eventually be found in Western Australia. The State's sedimentary basins cover extensive areas and contain thick accumulations of sediments, most of which are marine. No-one can claim that oil has been easy to find in these basins to date, but on a statistical basis they would be expected to contain large reserves of oil and gas.

One thing is clear; exploration should intensify in this State during the next few years. World-wide the consumption of oil is doubling every 10 years. Over the next 20 years it has been estimated that the world will consume about 500 billion barrels of oil and 750 trillion cubic feet of gas, which is about equal to all the present known reserves of oil and 75% of the gas. In order to keep pace with consumption and maintain a comparable reserves-to-production ratio as that held today, it will be necessary for the oil industry in the next 20 years to find about 3 times as much oil and gas as has been found in the past 100 years. In order to obtain and maintain self-sufficiency in Australia it has been estimated that we need to find about 20 billion barrels of oil in the next 20 years. This compares with the country's present known reserves of about 1.8 million barrels.

With this great need for further discoveries there must be an increasing interest in the prospective areas of Australia. Many petroleum geologists, including myself, regard Western Austra-

lia as having the best potential for future discoveries in the Commonwealth. Large areas of our sedimentary basins are still relatively unexplored, and in only a few areas has there been really intensive exploration. Consequently the tempo of exploration in the major sedimentary basins of the State should increase significantly during the next 10 years. On the basis of present knowledge the best prospects for future discoveries appear to be on the continental shelf in the Perth, northern Carnarvon, Canning, and Bonaparte Gulf Basins, although some onshore parts of these basins are also very promising. I believe that there are excellent prospects for the future discovery of substantial oil and gas reserves in these areas.

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